TITLE OF THE INVENTION

LIQUID CRYSTAL DISPLAY DEVICE

BACKGROUND OF THE INVENTION

The present invention relates to liquid crystal display device, particularly, to liquid crystal display device, a viewing angle of which is widened, and light utilization efficiency of which is improved by re-utilization of light using polarizing conversion and polarizing wave length selectivity.

Currently, technical advancement in liquid crystal display device, particularly in color liquid crystal display device, is significant, and display devices having the almost same image quality as CRT have been realized. The liquid crystal display device has been enlarging its commercial market based on features of thinness, light weight, and low consuming power. However, the liquid crystal display itself is still inferior to CRT in display performance such as moving image display, viewing angle, and color reproduction. Therefore, the liquid crystal display device still has issues to improve its display performance as well as decreasing its production cost.

The direct view type color liquid crystal display devices occupying the present market can be divided roughly into two types, i.e. an active matrix driven liquid crystal display device using TFT (thin film transistor) and a multiplex driven STN (super twisted

nematic) liquid crystal display device. In accordance with both of these display devices, polarizers are arranged at both sides of an element, which is composed of a liquid crystal layer held by glass substrates, and display is performed by modulating a polarization of linearly polarized light.

In the liquid crystal display device using the TFT, a TN (twisted nematic) mode is a representative one. However, both of the TN and STN modes have a narrow viewing angle, and other problems such as image reversal in grayscale display and multicolor display, and decrease in contrast ratio.

As a viewing angle widening mode using the TFT, various viewing angle widening modes such as a VAN (vertical aligned nematic) mode, an IPS (in-plane switching) mode, and others are used. In accordance with the above VAN and IPS modes for widening the viewing angle, grayscale reversal depending on viewing angle is scarcely generated, but color shift and decrease in contrast ratio are generated.

A method using a composition of collimated light source and a screen arranged on liquid crystal display element has been disclosed in PCT/US94/7369 as a prior art for realizing display with a widened viewing angle. Regarding screen technology of widened viewing angle, a method is disclosed in USP 2,378,252.

Conventional liquid crystal display device displays images by controlling polarized light of transmitted

light from an illumination device. In estimating light loss of a color liquid crystal display device, the light loss by a polarizer is approximately 60 %. In a case of color display, the color filter loss in a display device provided with plane-divided color filters is equal to or more than 70 %. Approximately 88 % of light is lost by arranging the polarizer and the color filters. Accordingly, even if the light loss generated by any other reason is removed, projected light from the illumination device can be utilized only approximately 12 % because of the absorption loss by the polarizer and the color filters.

On the other hand, demands for the liquid crystal display device of note-type personal computer are not only thinness and light weight, but also low consuming power and high brightness in display. Furthermore, a demand of decreasing consuming power for the display of desk top computer and work station is high. Accordingly, decreasing consuming power of the liquid crystal display device is indispensable in addition to widening the viewing angle.

Regarding the above issues, methods for decreasing the absorption loss of the polarizer and color filter in order to realize improvement in brightness are disclosed in JP-A-6-130424 (1994) and JP-A-6-167718 (1994). In accordance with the above methods, the efficiency of light utilization is improved with re-utilizing reflected light by controlling reflection-transmission of circular

polarized light in a specified direction of a specified wavelength by a cholesteric liquid crystal layer in order to utilize the light of the specified wavelength efficiently.

In order to realize the improvement in brightness, a method relating to the polarizing conversion using a cholesteric liquid crystal is disclosed in JP-A-3-45906 (1991). A prior art, wherein a composition using a cholesteric filter to a back light composition, is disclosed in JP-A-7-36032 (1995).

FIG. 32 indicates a cross sectional structure of liquid crystal display having a widened viewing angle disclosed in the prior art, i.e. PCT/US94/7369. The display has a problem that the consuming power of the back light is significantly increased for obtaining a more bright display, because the transmission factor of the screen is low in addition to complexity in the collimating structure and the screen structure. The liquid crystal display element comprises; a composition, wherein a liquid crystal layer 13 is interposed between two transparent substrates 11A, 11B, and two polarizers are arranged at both sides of them (not shown in the figure); a screen 10AA comprising transparent portions in a quadrangular pyramid at displaying plane side and black absorbing bodies covering intervals of them; and a collimated illumination device comprising lamps 51 provided at both sides of a waveguide, and transparent media in a quadrangular pyramid adhered onto the waveguide.

In accordance with the liquid crystal display device of the above structure, decrease in resolution by thickness of the substrate 11 is suppressed by the collimated illumination device, the viewing angle of which is widened by the screen 10AA. In order to obtain a high resolution with the above structure of the prior art, a strict collimation is required for the back light depending on the thickness and the index of refraction of the transparent substrate 11A. Simultaneously, more decreasing the consuming power, more widening the viewing angle, and improving more the resolution are required. It has been understood that increase in input power to the lamps influences an undesirable effect to the display such as increase in the temperature by heating (for instance, being a inferior image quality, shortening life of the lamp) in addition to increase in the consuming power.

In accordance with the structures disclosed in previously described JP-A-3-45906 (1991) and JP-A-7-36032 (1995) for improving the efficiency of light utilization, the reflected light is re-utilized using the cholesteric liquid crystal operating as a reflective polarizer. On the other hand, a light control element is used for the liquid crystal display of the note type personal computer in order to improve a brightness at a normal angle toward display surface with a decreased consuming power. As the light control element used most generally, BEF (commercial name) of 3M Company can be

exampled. In the light control element described above, the illumination device has a directivity at a normal angle toward a display surface in order to obtain a highly bright display with a low consuming power. However, in accordance with the above prior art, any efficiency of polarizing conversion has not been considered, when these light control elements are used for improving the brightness at a normal angle. Furthermore, any efficiency of polarizing conversion has not been considered, when the light control element are used.

In the light control element, a film having stripes, the cross section of which is a triangle shape, is used. Generally, PET (polyethylene terephthalate) is used as the material for the film, and has a biaxial birefringence. Accordingly, when its optical axis is shifted from the incident angle of incident linearly polarized light, the polarization is changed, and, as the result, decrease of the efficiency of polarizing conversion is caused. Furthermore, it was found that the efficiency of the polarizing conversion was decreased if two light control elements were used in a manner intersecting at right angles.

Compositions for decreasing the absorbing loss by color filter and improving the efficiency of light utilization are disclosed in previously described JP-A-6-130424 (1994) and JP-A-6-167718 (1994). Feature of the above compositions are in an arrangement of color selective layer at outside and inside of the substrate.

The compositions of the prior art are indicated in FIG. 37 and FIG. 38. In accordance with the structure indicated in FIG. 37, a liquid crystal 503 is interposed between glass substrates 501, 504, a selective layer 500 is arranged at projection side, a cholesteric layer 50t, i.e. a color selective layer and a filter layer 505 are arranged at incident side, and a light source 507 and a reflector 508 are arranged at rear side of the cholesteric layer 506. In a case of the composition, wherein the cholesteric layer 506, i.e. the color selective layer, is arranged at outside of the glass substrate 504 as indicated in FIG. 37, the projected light 510 viewed at a normal angle of display surface does not have any problems such as mixing colors in displaying color, because the projected light passes through a pixel, wherein the cholesteric layer 506 and the liquid crystal 503 are same (a region displaying the same color). However, in a case when an obliquely projected light 509 viewed at an oblique angle, for instance, the light transmitted through a red (or green, blue) color selective layer 506 is controlled by a modulating signals of green (or blue), i.e. an adjacent pixel. Accordingly, when viewing at an oblique angle, a right color is not necessarily displayed depending on the viewing angle, because of the thickness of the substrate 504 (generally the thickness of the glass substrate is 1.1 mm, or 0.7 mm, and the pixel pitch is approximately 100 μm).

In order to avoid the influence of the thickness of

the glass substrate 504, a composition wherein the color selective layer 512 and a retardation film 511 are built-in has been disclosed as indicated in FIG. 38. Other constituents are as same as the composition indicated in FIG. 37. However, any of the problem concerning the oblique incident relating to the characteristics of the light source has not been considered. In accordance with the composition indicated in FIG. 38, the display is performed with controlling the polarization to the liquid crystal layer 503 by the color selective layer 512 and the retardation film 511, and controlling the polarization by the liquid crystal layer 503. However, the cholesteric liquid crystal layer used as the color selective layer 512 has an undesirable degree of polarization to the oblique incident light, and moreover, unnecessary light leakage of color is generated. That means, against the oblique incident light, polarization other than a desired polarization is generated, leakage of color other than a desired color is generated, and depression in display quality represented by decreases in contrast ratio, color reproduction, and viewing angle characteristics is generated. Furthermore, any uses of the polarized light effectively is not considered at all.

SUMMARY OF THE INVENTION

One of the objects of the present invention is to provide a liquid crystal display device capable of

displaying in a wide viewing angle with a low consuming power.

Other one of the objects of the present invention is to provide a liquid crystal display device having a high brightness with a high polarizing conversion efficiency by specifying optimum axes arrangement of a light control element and a polarizer, when the light control element is utilized for improving brightness at a normal angle.

Other one of the objects of the present invention is to provide a liquid crystal display device capable of realizing improvement of the efficiency of light utilization and the brightness at a normal angle by using a waveguide, which is capable of maintaining polarization of light reflected from a reflective polarizer and of improving directivity.

Other one of the objects of the present invention is to provide a color liquid crystal display device having a wide viewing angle and a high display quality even if the display is viewed at an oblique angle by eliminating deterioration in display quality (unclearness) based on the thickness of the glass substrate and deterioration in display quality (decreased contrast ratio, deteriorated display color) at an oblique angle; aiming at decreasing the absorbing loss by the polarizer and the color filters, and improving the efficiency of light utilization.

In order to realize the above objects, the following measures are used in the present invention.

A liquid crystal display device comprising liquid crystal display elements for controlling polarized light, and an illumination device arranged at a rear side of the liquid crystal display elements; wherein a screen is provided to the liquid crystal display element, a reflecting means is provided to the illumination device at a rear side, and a light control means and a reflective polarizing selection means are provided between the liquid crystal display element and the illumination device; is composed that the polarized light transmission axis of the reflective polarizing selection means is arranged so as to make the polarized light transmission efficiency of the projected light from the illumination device high.

Furthermore, the liquid crystal display device is composed so that; a direction of the longitudinal axis of pixel of the liquid crystal display element is approximately in parallel with the polarized light transmission axis of the reflective polarizing selection means; the polarized light transmission axis is approximately in parallel or approximately perpendicular with an optical conversion axis of the light control means; the light projected from the illumination device is strongly directed at least in a direction of minor axis of the pixel; and the screen has a function to broaden the projected light at least in a direction of minor axis of the pixel.

Furthermore, the liquid crystal display device is

composed in a manner that the screen absorbs external light, and transmits the light projected from the illumination device.

Furthermore, the liquid crystal display device is desirably composed in a manner that a birefringent medium is arranged at a rear side of the light control means by using the reflective polarizing selection means, which transmits linearly polarized light and reflects other linearly polarized light perpendicular to the above transmitted linearly polarized light.

Furthermore, the liquid crystal display device is composed in a manner that the birefringent medium is arranged in a direction of approximately 45 degrees to the polarizing axis of the reflected light so that the birefringent medium operates as an approximately a quarter wave plate.

The illumination device is composed so that the polarizing conversion efficiency is increased by maintaining the polarized light reflected from the reflective polarizer in the illumination device, and the directivity at all azimuth is enhanced by increasing the directivity at least in an axial direction and using concurrently the light control element. In order to improve the brightness at a normal angle, the illumination device comprising a flat plate shaped waveguide, and a light source arranged adjacently in the vicinity of the waveguide, is composed so that the light projected from the light source is transmitted through the waveguide,

and projected through a light projecting plane of the waveguide; the light projecting plane of the waveguide is provided with a reflecting plane composed of fine declined planes having a large number of concave planes, convex planes or steps at its rear side; the reflecting plane is mirror-finished at least at the declined plane portion; and the reflector is provided to the rear plane of the waveguide directly or via an air layer.

Furthermore, a reflective color selection means corresponding to the pixel of the liquid crystal display is arranged, as a composition for improving the efficiency of the light utilization.

Furthermore, the screen is composed so that the oblique incident light is absorbed efficiently, and the incident light at the normal angle is transmitted efficiently. Particularly, the transmitted light at a normal angle from the liquid crystal display element is transmitted through a small aperture by refraction of light, and the oblique transmitted light is absorbed. The screen is composed in a manner of being covered with an absorbing material which absorbs most of external light when the screen is viewed from the front display plane side.

Functions of each members are explained hereinafter.

The light reflected from the stripe grooves on the rear plane of the waveguide has a high polarized component in the stripe direction, and the efficiency can be improved by coinciding the stripe direction with the polarized

light transmission axes of the reflective polarizer and the incident side polarizer of the liquid crystal display element. The transmission efficiency can be improved further by coinciding with stripe direction of the light control element. Generally, the light control element desirably does not have any birefringence, but even if any birefringence exists, the efficiency can be improved by coinciding its optical axis with the polarizing axis of the transmitted light or utilizing its birefringence for operating as a retardation plate.

The display is performed by controlling the polarizing condition of the polarized light transmitting the liquid crystal layer by controlling the orientating condition of the liquid crystal layer. The absorption type polarizing selection means is a so-called linear polarizer of absorbing unnecessary polarized light for transmitting one of linearly polarized lights intersecting in right angles each other and absorbing the other linearly polarized light, or a so-called circular polarizer of absorbing unnecessary polarized light for transmitting one of two circularly polarized lights and absorbing another circularly polarized light. The reflective polarizing selection means is a linear polarizer of reflecting unnecessary polarized light for transmitting a part of linearly polarized light intersecting, for instance, in right angles each other and reflecting the rest of the linearly polarized light, or a circular polarizer of reflecting unnecessary

polarized light for transmitting a part of the circularly polarized lights and reflecting rest of the circularly polarized light. The reflective color selection means is a so-called color filter reflecting polarized light in an unnecessary region of wavelength, which transmits a part of linearly polarized light (or circularly polarized light) having a specified wavelength (for instance, a center wavelength of 550 nm ± approximately 40 nm) and reflects linearly polarized light (or a circularly polarized light) having other region of wavelength. More details will be explained later referring to embodiments, but the reflective color selection means utilizes selective reflection of cholesteric layer and characteristics of multilayered dielectric film. Generally, because the color selection means utilizing such selective reflection of the cholesteric layer and characteristics of multilayered dielectric film has a large viewing angle dependence, coloring material absorbing light other than the desired transmitting light can be mixed or laminated.

The screen is a means for diffusing or difracting incident light such as, for instance, an arrangement of beads or rod lenses, the projection side of which is covered with a black absorbing material, or a scattering medium having a hologram or non-uniform index of refraction. The screen desirably maintains the polarization of the polarized light, and has a role to make the viewing angle wide by broadening the projected

light having a high collimation from the illumination device at the projecting side of the liquid crystal display element. Furthermore, the screen operates to absorb external light efficiently. A means for increasing collimation of the projected light as the illumination device comprises, for instance, a wedge shaped waveguide having stripes of microgrooves at its rear plane, and an arrangement of lens sheet having stripes of triangle shapes intersecting with stripes of grooves as the light control means on the waveguide. Thereby, the projected light having a high collimation in a direction perpendicular to the direction of the stripes can be obtained by the stripes of the microgrooves of the waveguide, and furthermore, the collimation in a direction intersecting the above projected light can be improved by the function of the lens sheet. Accordingly, the illumination device having a high collimation at all azimuth can be obtained.

When the collimated light from the illumination device is undesirable, the problems caused by unclearness of the displayed image and mixing colors are as indicated in the embodiment shown in FIG. 37 and FIG. 38. Therefore, the collimated light from the illumination device is important for obtaining clear image display. Using the liquid crystal display element indicated in FIG. 39, necessary collimation of the light source was investigated. First, in accordance with the present invention, a composition is composed by arranging the

liquid crystal layer 13 between the transparent substrates 11A, 11B, at the projection side of which, the absorption type polarizing selection layer 14A, and the screen 10 are arranged; and, at the incident side of which, the retardation film 71, i.e. a reflective color selection layer 70, and cholesteric layer 72 are arranged. Here, the thickness 11At, 11Bt of the transparent substrates 11A, 11B are made both t, the pixel pitch is made d, incident angle 430 of the incident light to the liquid crystal display element 20 is expressed by θ_1, incident angle 431 of the incident light to the transparent substrate 11B is expressed by θ_2, and the index of refraction of the transparent substrates 11A and 11B are expressed both n. Here, three pixels of R, G, and B are gathered to form a picture element. Generally, one pixel had a ratio of vertical direction to lateral direction of 3 : 1, and the short side of the pixel was designated as the pixel pitch d. The color mixing and the unclearness based on the thickness of the substrate by oblique incident light must be restricted in at least two pixels at an angle where the brightness is 1/2 of the peak brightness. Otherwise, the displayed image becomes unclear. Accordingly, the incident angle θ_1 of the incident light must satisfy the following equation (1).

$$\theta_1 \leqq \sin^{-1}(n \bullet \sin(\tan^{-1} (2d/t))) \qquad \ldots(1)$$

Assuming that the refractive index of the transparent

substrate n = 1.53, thickness t = 700 μm, and the pixel pitch d = 100 μm, the incident angle θ_1 of the incident light must be equal to or less than 24.9 degrees. Otherwise, the incident light overlapped with pixels of other colors, and decrease of the image quality such as mixing colors, unclearness, and the like are generated. Accordingly, the collimated light from the illumination device must be in the angular range which satisfies the condition (1) with at least a half width (an angular range of brightness which is 1/2 of the peak brightness). Therefore, with the transparent substrate and pixel used in the present embodiment, equal to or less than 24.9 degrees is necessary. The screen desirably absorbs the oblique incident light effectively to suppress decrease in resolution.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 2 is a cross section of the screen applied to the liquid crystal display device of the present invention,

FIG. 3 is a cross section of the screen applied to the liquid crystal display device of the present invention,

FIG. 4 is a plan view of the screen applied to the liquid crystal display device of the present invention,

FIG. 5 is a partially exploded view of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 6 is a cross sectional view of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 7 is a cross section of the illumination device indicating an embodiment of the present invention,

FIG. 8 is a cross section the illumination device indicating an embodiment of the present invention,

FIG. 9 is a cross section of the illumination device indicating an embodiment of the present invention,

FIG. 10 is a cross section of the reflective polarizer applied to the liquid crystal display device of the present invention,

FIG. 11 is a cross section of the reflective polarizer applied to the liquid crystal display device of the present invention,

FIG. 12 is a cross section of the reflective polarizer applied to the liquid crystal display device of the present invention,

FIG. 13 is a cross sectional illustration indicating an operation of the liquid crystal display device of the present invention,

FIG. 14 is a cross sectional illustration indicating an operation of the liquid crystal display device of the present invention,

FIG. 15 is a cross sectional illustration indicating an operation of the liquid crystal display device of the present invention,

FIG. 16 is a cross sectional illustration indicating

an operation of the liquid crystal display device of the present invention,

FIG. 17 is a cross section of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 18 is a cross sectional illustration indicating an operation of the liquid crystal display device of the present invention,

FIG. 19 is a cross sectional illustration indicating an operation of the liquid crystal display device of the present invention,

FIG. 20 is a partially exploded view of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 21 is a partially sectional perspective view of the illumination device indicating an embodiment of the present invention,

FIG. 22 is a partially sectional perspective view of the illumination device indicating an embodiment of the present invention,

FIG. 23 is a partially sectional perspective view of the illumination device indicating an embodiment of the present invention,

FIG. 24 is a partially sectional perspective view of the illumination device indicating an embodiment of the present invention,

FIG. 25 is a cross section of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 26 is a cross section of the liquid crystal display

device indicating an embodiment of the present invention,

FIG. 27 is a cross section of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 28 is a perspective illustration indicating an operation of the screen applied to the liquid crystal display device of the present invention,

FIG. 29 is a perspective illustration of the liquid crystal display device indicating an embodiment of the present invention,

FIG. 30 is a graph indicating characteristics of the illumination device of the present invention,

FIG. 31 is a graph indicating characteristics of the illumination device of the present invention,

FIG. 32 is a cross section of the conventional liquid crystal display device,

FIG. 33 is a cross sectional illustration indicating an operation of the conventional liquid crystal display device,

FIG. 34 is a cross sectional illustration indicating an operation of the conventional liquid crystal display device,

FIG. 35 is a partially exploded view of the conventional liquid crystal display device,

FIG. 36 is a partially exploded view of the conventional liquid crystal display device,

FIG. 37 is a cross sectional illustration indicating an operation of the conventional liquid crystal display device,

FIG. 38 is a cross sectional illustration indicating an operation of the conventional liquid crystal display device, and

FIG. 39 is a cross sectional illustration indicating a composition of the conventional liquid crystal display device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First, the illumination device is explained, hereinafter.

The illumination device is called as a back light, and the illumination device can be classified roughly into two kinds, i.e. direct-below type back light and edge-light type back light. The direct-below type back light is composed so that light sources are provided inside the illuminating plane. On the other hand, the edge-light type back light is composed so that light sources are provided outside the illuminating plane, the waveguide, i.e. the illuminating plane, is made of transparent acrylic resin and the like, cylindrical light-sources such as fluorescent lamps (cold-cathode discharge tube, or hot-cathode discharge tube) and the like are arranged at one-side or two sides of the waveguide, and lamp covers composed of reflectors are arranged at outside of the light-sources for propagating light into the waveguide. The edge light type back light is effective for the liquid crystal display device required

to be thin, and the direct-below type back light is effective for the liquid crystal display device required to be light weight, and small frame.

The edge-light type back light has been mainly used for the conventional liquid crystal display device, and the waveguide is composed of being applied with white ink at its rear plane in order to obtain homogeneity in the plane. Furthermore, in order to improve the efficiency of the light utilization, the reflective polarizer is used; the reflective polarizer is such as the polarized light separator by dielectric multilayers disclosed in USP 5,486,949, and "SID92 Digest" pp.427, and cholesteric film quarter wave plate disclosed in JP-A-7-36032(1995), and "Asia display 95" pp. 735. Hereinafter, the former, i.e. the polarized light separator by dielectric multilayers, is called a reflective polarizer type 1, and the latter, i.e. the cholesteric film quarter wave plate, is called a reflective polarizer type 2.

S polarized light, which indicates a polarization of a light, is the polarized light perpendicular to the incident plane (the incident plane means a plane formed by an incident light and an incident normal on the boundary plane), and P polarized light is the polarized light in parallel to the incident plane.

Assuming an incident angle θ when incident light from medium N_0 to medium N_1 at a boundary plane of a transparent medium having an index of refraction N_0 and a transparent medium having an index of refraction N_1, it is well known

that, when tangent of the incident angle θ is equal to N_1 / N_0 (i.e. tan $\theta = N_1 / N_0$), no reflective component exists in P polarized light, all the reflection light becomes S polarized light, and the transmitted light becomes rest of the S polarized light and the P polarized light. The incident angle at the above case is called a Brewster angle. A reflective polarizer capable of transmitting only the P polarized light and reflecting the S polarized light by controlling the phases of respective type of the polarized light can be manufactured by utilizing the Brewster angle, laminating various media having different indexes of refraction each other, and controlling thickness of the laminated film with a wavelength order.

Examples of the reflective polarizer type 1 are indicated in FIG. 10 and FIG. 11.

FIG. 10 indicates a reflective polarizer 31 formed by laminating a large number of layers with aligning their optical axes, the layers include an uniaxial anisotropic transparent medium 31A having an anisotropy in the index of refraction and an isotropic transparent medium 31B. Non-polarized light 140, i.e. an incident light to the reflective polarizer 31, only a part of linearly polarized light 141 which is transmitted through the polarizer, and the linearly polarized light 142 intersecting the polarized light 141 in right angles is reflected.

FIG. 11 indicates a structure, wherein two kinds of prism shaped transparent media having different indexes

of refraction each other are laminated alternately. The reflective polarizer 32 transmits only the P polarized light 144, and reflects the S polarized light 145 intersecting the above polarized light with right angles among the non-polarized light 143.

The reflected linearly polarized light is converted to elliptically polarized light (including linearly polarized light and circularly polarized light) by retardation film, when treated with a scattering film as a depolarizer, or retardation film to change the polarization of the light. Then, the light is entered into the reflective polarizer again, only one component of the linearly polarized light is transmitted, other component of the linearly polarized light intersecting with right angles are reflected and back to the waveguide. Theoretically, almost all the light can be converted to the linearly polarized light and projected by repeating the above cycles.

However, because of the presence of absorption at various portions, practically, an arrangement of retardation film operating as a quarter wave plate so as to be a half wave plate after reciprocally transmitted is desirable, in order to convert all the reflected linearly polarized light to the linearly polarized light intersecting with right angles.

On the contrary, FIG. 12 indicates an example of the reflective polarizer type 2.

The structure indicated in FIG. 12 is composed of

laminating a cholesteric liquid crystal polymer 33A disclosed in "Asia Display 95 Digest" pp. 735 onto a cholesteric liquid crystal polymer 33B having a pitch different from the above cholesteric liquid crystal polymer 33A so as to indicate selective reflection in a visible wavelength region, in order to transmit circularly polarized light in a certain rotation in the non-polarized light 146 and to reflect other circularly polarized light 148 in the rotation reverse to the above rotation; and a laminating quarter wave plate thereon in order to transmit the linearly polarized light 147 in a direction.

Operation of the reflective polarizer type 2 is to generate linearly polarized light in a direction by transmitting a right-handed circularly polarized light (or a left-handed polarized light), reflecting the left-handed circularly polarized light (or a right-handed circularly polarized light), and processing the transmitted light with the quarter wave plate. On the other hand, the reflected left-handed circularly polarized light (or a right-handed circularly polarized light) is further reflected by a mirror reflector to be a right-handed circularly polarized light (or a left-handed circularly polarized light), transmitted through the reflective polarizer type 2, and processed with the quarter wave plate. Finally, all the light is converted to the linearly polarized light. Even if the reflector is not the mirror reflector, the reflected light becomes

elliptically polarized light (including linearly polarized light and circularly polarized light), and enters into the reflective polarizer again. Then, only the right-handed circularly polarized light (or in a left-handed circularly polarized light) is transmitted, and the left-handed circularly polarized light (or in a right-handed circularly polarized light) is reflected to the waveguide. After repeating the above processes, almost all the light is converted to the right-handed circularly polarized light (or a left-handed circularly polarized light), and projected as linearly polarized light in a direction after processed with the quarter wave plate. In accordance with the presence of no small absorption of light with the reflector, the reflector is desirably a mirror reflector, in order to convert all the reflected circularly polarized light in a left-handed circularly polarized light (or a right-handed circularly polarized light) to the right-handed circularly polarized light (or a left-handed circularly polarized light).

In order to clarify differences in the composition and advantages of the liquid crystal display device of the present invention from that of the prior art, the conventional liquid crystal display device is explained hereinafter referring to FIG. 33 - FIG. 36.

FIG. 35 is a partially exploded view indicating a composition of a conventional edge-light type back light.

The edge-light type back light in accordance with the above composition comprises a waveguide 53 made of a piece

of transparent acrylic resin having white ink on its rear plane; a reflector 54 arranged on rear plane of the waveguide 53; a light source 51 arranged at least one of side planes of the waveguide 53; and a diffusion film 56 arranged on the projecting plane of the waveguide 53.

As a component for increasing the brightness at a normal angle, light control elements 40 are arranged in parallel or perpendicular to the long side of the light source 51. To the liquid crystal display element 20, a TN mode having a 90 degrees twist is applied as the most general mode. The liquid crystal display element 20 is so-called normally white mode, wherein the polarizing axis 14BB of the lower polarizer is arranged so as to intersect perpendicularly with the polarizing axis 14AA of the upper polarizer. Accordingly, the transmission axis 31 of the polarized light at the reflective polarizer 30 is arranged in parallel with the polarizing axis 14BB of the lower polarizer. That is, the direction of the stripes 41 of the light control element 40 (hereinafter, the direction, which an optical path intersecting perpendicularly with the above direction 41 is converted to, is called an optical path conversion axis of the light control element) is composed so as to intersect with 45 degrees with the transmission axis 31 of the polarized light of the reflective polarizer 30.

In a case that the reflective polarizer type 1 is used as the reflective polarizer 30 in the above composition, when the light 194 , which is non-polarized light, is

projected from the waveguide to the reflective polarizer 31, only a part of the linearly polarized light 195 is transmitted through the polarizer 31, and the rest of the linearly polarized light 196 intersecting perpendicularly with the polarized light 195 is reflected by the reflective polarizer 31, as indicated in FIG. 34. It has been understood that the optical axis of the birefringence of the light control element 40 is in the direction of the light control axis. At that time, the reflected light 196, which is linearly polarized light, can not maintain its polarization and the linearly polarized light becomes elliptically polarized light based on the birefringence of the light control element 40, because the direction of the polarizing axis forms an angle of 45 degrees with the light control element 40. The elliptically polarized light becomes non-polarized light 197 by an optical diffusion with the white ink on the rear plane of the waveguide and the diffuser 56, and reflection with the reflector 54. Accordingly, only a component in parallel with the polarized light transmission axis of the reflective polarizer 31 is transmitted, and becomes linearly polarized transmitted light 195A, which is the polarized light as same as the transmitted light 195. The reflected linearly polarized light 196A intersecting perpendicularly with the linearly polarized light of the transmitted light 195A becomes non-polarized light 197A by the same processes as the reflected light 196, and further becomes linearly

polarized transmitted light 195B, which is the polarized light as same as the transmitted light 195 and 195A by the same processes as above. Furthermore, the reflected light 196B becomes non-polarized light 197B by the same processes as the reflected light 196A.

Theoretically, all the light can be projected after converted to the same linearly polarized light by repeating the above processes. However, when the efficiency of the projected light from the liquid crystal display device was measured practically, it was found that the amount of luminous flux was increased only approximately 30 % by the presence of the reflective polarizer 31. The direct reasons for the decrease in the efficiency can be assumed to be based on the absorption by the reflector 54, waveguide, white ink, diffuser, and others, and further, on the transmission of unnecessary polarized light depending on the incompleteness of the reflective polarizer 31. That is, although the absorption of the respective member per each of the transmission and the reflection is small, the polarizing conversion can not be performed effectively by only once reflection with the conventional composition, and a large number of repetition of the transmission and reflection are performed for the conversion. Consequently, the absorption by the respective members are increased. That is, the fundamental reason for the decrease in the efficiency is based on that, because the direction of the stripes 41 of the light control element 40 intersects by

an angle of 45 degrees with the polarized light transmission axis 31 of the reflective polarizer 30 as indicated in FIG. 35, the linearly polarized light is converted to elliptically polarized light by the birefringence. Therefore, the conversion can not be performed effectively by only once reflection, and the polarizing conversion is performed by a large number of repetition of the reflection. Accordingly, it is assumed that the efficiency of the polarizing conversion is decreased by receiving significantly the influence of the absorption by the respective members.

In a case that the reflective polarizer type 2 is used as the reflective polarizer 30 in the above composition, when the projected light 190, which is non-polarized light, is projected from the waveguide, only a part of the circularly polarized light is transmitted and converted to the linearly polarized light 191 by the retardation film 33A as indicated in FIG. 33. The rest of the circularly polarized light 192 is reflected by the reflective polarizer 33. At that time, the reflected light 192, which is circularly polarized light, becomes elliptically polarized light, because the polarization can not be maintained based on the birefringence of the light control element 40. Furthermore, the reflected light 192 becomes non-polarized light 193 by optical diffusion with the white ink at the rear plane of the waveguide and the diffuser, and reflection by the reflector 54. Accordingly, a part of the circularly

polarized light is transmitted through the reflective polarizer 33, and converted to the linearly polarized light 191A as same as the linearly polarized light 191 by the retardation film 33A. The circularly polarized light 192A in a reverse rotation is reflected, and becomes non-polarized light 193A by the same processes as the reflected light 192. Similarly, 191B, 192B, and 193B are obtained.

Theoretically, all the light can be converted to the same linearly polarized light by repeating the above processes with this composition. However, when the efficiency of the projected light from the liquid crystal display device was measured practically, it was found that the amount of luminous flux was increased only approximately 30 %, as same as the case using the reflective polarizer type 1. The reasons can be assumed to be based on the absorption loss by the large number of reflection as same as the case of the reflective polarizer type 1. In the case of the reflective polarizer type 2, it is assumed that the reason can be moderated by using isotropic medium having no birefringence in the light control element 40, or arranging the retardation film so that the reflected light must intersect perpendicularly or be in parallel with the light control axis before entering into the light control element 40, because the circularly polarized light is reflected.

Conventionally, a composition, wherein the light control elements are arranged so that each of the light

control axis intersects perpendicularly each other as the light control elements 40, 42 indicated in FIG. 36, has been considered as a composition for increasing further the brightness at a normal angle. In accordance with the above composition, the brightness at a normal angle can be increased by making a piece of light control element, conventionally it has only one axis directional directivity (horizontal or vertical direction), have directivity at approximately all azimuth.

The conventional edge-light type back light comprises a waveguide 53 made of a piece of transparent acrylic resin having white ink on its rear plane; a reflector 54 arranged on rear plane of the waveguide 53; a light source 51 arranged at least one of side planes of the waveguide 53; and a diffuser 56 arranged on the projecting plane of the waveguide 53. The light control axis of each of the light control element is arranged in parallel or perpendicularly with the long side of the light source 51.

To the liquid crystal display element 20, a TN mode having a 90 degrees twist is applied as the most general mode. The liquid crystal display element 20 in this case is so-called normally white mode, wherein the polarizing axis 14BB of the lower polarizer is arranged so as to intersect perpendicularly with the polarizing axis 14AA of the upper polarizer. Accordingly, the transmission axis 31 of the polarized light at the reflective polarizer 30 is arranged in parallel with the polarizing axis 14BB

of the lower polarizer. That is, the directions of the stripes 41, 43 of the light control element 40, 42 are composed so as to be in parallel or intersect perpendicularly with the transmission axis 31 of the polarized light of the reflective polarizer 30.

Even if the liquid crystal display device is composed as above, the efficiency of light utilization is increased only approximately 30 % by applying the reflective polarizer as same as FIG. 35. In accordance with the above composition, in a case when the reflective polarizer type 2 is used as the reflective polarizer 30, it is necessary to convert to the linearly polarized light by arranging the retardation film just before the light control element 40. However, the efficiency of light utilization is increased only approximately 30 % by applying the reflective polarizer type 1 is used. The reason for obtaining the above efficiency has been found that the light control element 40, 42 are anisotropic media, and their polarization are changed if projective components of their optical axes are in parallel or perpendicular with the incident linearly polarized light. It has been found that the influence of the change in the polarization is small when the number of the light control element is one, but when the number is two, the influence is enhanced in comparison with the case of the number is one. The reason to enhance the influence can be assumed that, when the apex angle of the light control element 40 is 90 degrees, the perpendicularly incident light is not projected

because all the light is reflected, multi-reflection is repeated by using two pieces of the light control elements, and the efficiency is decreased by receiving significantly the influence of the change in the polarization.

As described above, it was found that the efficiency of the light utilization could not be increased on account of a large number of reflection, when the reflective polarizer and the light control element were used for improving the efficiency of the light utilization and improving the brightness at a normal angle. Also, it was found that the efficiency could not be increased on account of misalignment of the optical conversion axis of the light control element with the transmission axis of the polarized light.

Hereinafter, theory of the present invention, wherein the reflected light can be re-used effectively by only once reflection, is explained referring to FIG. 13 and FIG. 14.

First, the operation when the reflective polarizer type 1 is used as the reflective polarizer 30 is explained referring to FIG. 13.

Linearly polarized light 161, which is a part of the non-polarized light 160 projected from the waveguide, is transmitted through the reflective polarizer 31, and other linearly polarized light 162, which is the rest of the non-polarized light 160 and intersects perpendicularly with the transmitted light 161, is

reflected by the reflective polarizer 31. Then, the reflected light 162 is converted to circularly polarized light 163 by the birefringent medium 60 operating as the quarter wave plate. The circularly polarized light 163 is reflected by the reflector 54 to be the circularly polarized light 164 having rotation in a direction reverse to the circularly polarized light 163. The circularly polarized light 164 is converted to the same linearly polarized light 165 as the transmitted light 161 by the birefringent medium 40, and transmitted through the reflective polarizer 31 to be the linearly polarized light 166. In accordance with the above processes, all the light is converted to the same linearly polarized light by reflection of only once, and efficient polarizing conversion can be achieved.

Then, the operation when the reflective polarizer type 2 is used as the reflective polarizer 30 is explained referring to FIG. 14.

Circularly polarized light 171, which is a part of the non-polarized light 170 projected from the waveguide, is transmitted through the cholesteric layer 33B, and converted to the linearly polarized light 172 by the birefringent medium 33A operating as the quarter wave plate. Other circularly polarized light 173 reflected by the cholesteric layer 33B is reflected by the specular reflector 54, and converted to the circularly polarized light 174 having rotation in a direction reverse to the circularly polarized light 173. The circularly

polarized light 174 is transmitted through the cholesteric layer 33B, converted to the same linearly polarized light 176 as the transmitted light 172 by the birefringent medium 33A, and projected. In accordance with the above processes, all the light is converted to the same linearly polarized light by reflection of only once, and efficient polarizing conversion can be achieved. When the reflective polarizer type 2 is used, the linearly polarized light is desirably converted before entering into the light control element, or at least uniaxial anisotropic, further, isotropic media is desirably applied as the light control element. When uniaxial anisotropic medium is used as the light control element, the light control element desirably operates as the quarter wave plate so as to make the linearly polarized light converted to circularly polarized light after transmission.

As described above, the light control element must be arranged so as not to be effected by influence of the birefringence, in order to make the polarizing conversion performed efficiently by the reflection of only once. Furthermore, it was found that maintaining the polarization by the waveguide, diffuser, and the like was optimum for improving the efficiency. When the brightness at a normal angle is increased by increasing the directivity at all azimuth, two pieces of the light control elements 40 are conventionally used. However, when two pieces are used, the efficiency was decreased

by a light loss due to multireflection. Therefore, a composition, wherein the directivity in an uniaxial direction is increased by the waveguide, and the directivity in a direction perpendicular to the above is increased by the light control element, is effective.

An example of the waveguide of the present invention is explained hereinafter referring to FIG. 7-FIG. 9.

In order to reflect the reflected light from the reflective polarizer to the liquid crystal display element region again with maintaining its polarization, fine inclined planes 53B for specular reflection and flat mirror portions 53A are provided at the rear plane of the waveguide 53, and a specular reflector 54 is provided beneath the rear plane of the waveguide 53 as indicated in FIG. 7. In the above case, the inclined plane 53B has small area ratio in comparison with the flat portion 53A. The inclined plane 53B is for projecting light from the waveguide 53, and the specular reflecting flat portion 53A is for propagating light by reflecting all the light in the waveguide 53. Although the inclined plane and the flat plane can be made of metallic reflecting planes, total internal reflection having a highest reflection rate is desirably utilized, because the number of reflections is enormous when propagating in the waveguide.

The inclined portions 53A and slightly inclined flat portions 53B can be provided as indicated in FIG. 8.

In accordance with the above composition, almost all

the light reflected from the reflective polarizer is transmitted through the flat portion at the rear plane of the waveguide, and reflected by the reflector arranged beneath the rear plane of the waveguide to be projected from the waveguide again with maintaining the polarization. Therefore, the brightness can be improved by utilizing the light efficiently with scarce absorption by the polarizer at incident light side of the liquid crystal display element.

Furthermore, the inclined portions 53A and stepwise flat portions 53B can be provided as indicated in FIG. 9. In accordance with the above composition, almost all the light reflected from the reflective polarizer is transmitted through the flat portion at the rear plane of the waveguide, and reflected by the reflector arranged beneath the rear plane of the waveguide to be projected from the waveguide again with maintaining approximately the polarization. Therefore, the brightness can be improved by utilizing the light efficiently with scarce absorption by the polarizer at incident light side of the liquid crystal display element.

When the light 120 from the light source is projected to the flat mirror portion 53A at the rear plane of the waveguide 53, the light is totally reflected as indicated as 121 due to TIR (totally internal reflection), propagated in the waveguide 53, and projected as indicated as 110A from the waveguide 53 only when the light is projected to the fine mirror reflection plane 53B.

Otherwise, the transmitted light is propagated in the waveguide 53 as indicated as 111. The light is also totally reflected at upper plane of the waveguide 53 due to TIR(totally internal reflection). The light having an incident angle equal to or more than a total reflection angle θ_c, which is defined by the index of refraction of the waveguide 53, is totally reflected at the surface of the waveguide 53, and propagated in the waveguide 53. The light having an incident angle less than the total reflection angle θ_c is refracted at the upper plane of the waveguide, and projected from the waveguide. For instance, the totally reflection angle θ_c at a boundary of air (index of refraction n = 1) and transparent resin such as acrylic resin, polycarbonate, polyurethane, polystyrene, and the like (n = approximately 1.5) is given as follows:

$$\theta_c = \sin^{-1}(1/n) = 42°$$

The θ of the incident light into the waveguide is in the range given as follows:

$$-(90° - \theta_c) \leqq \theta \leqq +(90° - \theta_c)$$

Therefore, the incident light is totally reflected at the flat portion of the upper and lower planes of the waveguide.

Furthermore, referring to FIG. 9, the light is projected from the waveguide 53 as indicated as 110A only when the light is projected to the fine mirror reflecting plane 53B, and simultaneously, the transmitted light is reflected by the reflector at the rear plane of the

waveguide 53 to be the projected light 111A.

The most important composition of the present invention is making the optical conversion axis perpendicular to the polarizing direction by realizing an uniaxial direction with the waveguide, and realizing a direction intersecting the above uniaxial direction perpendicularly with the light control element, in order to improve the efficiency of the re-utilization when the reflective polarizer is used.

Utilizing a fact that a ratio of the length in the vertical direction and the length in the lateral direction of the pixel of the liquid crystal display element is generally 3:1, the illumination devices indicated in FIG. 7 - FIG. 9, which are capable of improving collimation of illuminated light at least in the direction of minor axis of the pixel, are used. These illumination devices have larger polarized component in a direction perpendicular to the figure than other direction, because stripe grooves are formed at their rear planes. Then, in order to improve the efficiency of the light utilization, a composition is formed, wherein the direction of the stripe grooves having the larger polarized component is aligned with the polarized light transmission axis of the polarizer of the liquid crystal display element. Furthermore, in order to improve the efficiency of the light utilization remarkably, a composition is formed, wherein the light control axis of the light control element is intersected approximately

perpendicularly with the polarized light transmission axis of the reflective polarizer. Furthermore, in order to improve the efficiency of the light utilization, a composition is formed; wherein the liquid crystal display elements are arranged on the collimator (illumination device), and an outer screen (or to inner if the maintaining performance of the polarization is high) is arranged on the projection side polarizer. In accordance with these compositions, widening the transmission light of the liquid crystal display element and increasing the viewing angle become possible. For the above screen, a screen is used; which absorbs external light, transmits perpendicular transmission light of the liquid crystal display element efficiently, and absorbs oblique incident light.

Furthermore, in a case when a reflective color selective means is applied in order to decrease the absorption loss of the absorption type color filter, and to improve the efficiency of the light utilization, the arrangement in consideration of the polarizing axis as same as the above compositions is desirable.

Hereinafter, practical embodiment of the present invention is explained.

First, the embodiment of the present invention is explained referring to FIG. 1.

In accordance with the present embodiment, the composition comprises an illumination device 50 having particularly collimated light arranged in a lateral

direction of the figure, the reflective polarizer 31 indicated in FIG. 10 comprising dielectric multilayered film as the reflective polarizing selective means 30, the liquid crystal display element 20, the light control element 40, the birefringent medium 60, and the screen 10 having a wide viewing angle.

As the illumination device 50 applied to the present embodiment, any of edge light type back light and direct-below type back light can be used. The illumination device 50 relating to the present embodiment is composed in a manner that, for instance, definite fine grooves in a perpendicular direction to the figure are provided at the rear plane of the waveguide 53 as indicated in FIG. 1, and metal (aluminum, silver, and the like) having a high reflective index is arranged as the rear plane reflector 54, in order to make the light projected from the light source 51 have a directivity at least in an uniaxial direction. A component projected to the left-declined portion at the rear plane of the conductive body 53, among the light projected from the light source 51, is reflected; and projected upwards as highly directed light (in a lateral direction of the figure). On the other hand, the component projected to the right-declined portion is propagated through the waveguide 53 to make the light in the plane uniform. In accordance with the waveguide having the stripe grooves as the present embodiment, the polarized light component perpendicular to the figure is enhanced. Accordingly, a desirable

composition can be obtained by arranging the lower polarizer 14B of the liquid crystal display element 20 in a direction parallel to the direction of the stripe grooves of the waveguide. The composition is explained later.

The illumination device of the present embodiment is composed in a manner that the light source 51 is extending in a direction perpendicular to the figure, and the reflector 52 is arranged around the light source so that the light 110 projected from the light source 51 is propagated to the waveguide 53. Cold cathode fluorescent lamps were used as the light source 51, but the light source was not restricted with it. Because the screen 10 is arranged at display plane side, it is necessary to improve the transmittance, to eliminate color mixing of the oblique incident light, and to make the light have directivity at least in a lateral direction of the figure. Therefore, the illumination device 50 of the present embodiment was composed so as to be capable of making the light projected from the waveguide 53 have a directivity at least in a lateral direction of the figure by forming fine grooves at the rear plane of the waveguide 53, which is composed of transparent acrylic resin, as indicated in FIG. 7 to FIG. 9.

In accordance with the above composition, the incident light to the declined portion 53B of the fine grooves, among the incident light 110 to the waveguide 53, is reflected by the declined angle 53D; and projected from

the waveguide 53 as the projected light 110A. On the other hand, the incident light to the flat portion 53A of the fine structure is totally reflected due to TIR, propagated to the right direction of the figure by being propagated through the waveguide 53, and projected as the projected light 110A only when the incident light is projected to the declined portion. The fine structure at the rear plane of the waveguide 53 had a pitch 53C of 200 μm, and a declined angle 53D of 40 degrees. However, the pitch 53C can be in the range of approximately 10 μm - 1000 μm, and the declined angle 53D can be in the range of approximately 20 degrees - 50 degrees.

Projection characteristics of the illumination device 50 used in the present embodiment is indicated in FIG. 30.

The characteristics in a vertical direction in the figure was 25A, the characteristics in a lateral direction in the figure was 25B, and the illumination device having a high directivity in an uniaxial direction could be realized. Furthermore, FIG. 31 indicates a projection characteristics when light control elements in a stripe shape 40 (commercial name of the 3M company is BEF) having an apex angle of approximately 90 degrees are applied in a manner to intersect the stripe grooves of the waveguide 53 perpendicularly. The characteristics in a vertical direction in the figure was 25C, the characteristics in a lateral direction in the figure was 25D, and the illumination device having a high directivity in a

direction perpendicular to the figure could be realized. In accordance with the present embodiment, the direction having the high directivity was aligned with the minor axis direction of the pixel of the liquid crystal display element.

As the liquid crystal display element 20, a pair of transparent substrates 11A, 11B; a liquid crystal layer interposed between the pair of transparent substrates; stripe shaped color filters 12 in a direction perpendicular to the figure; absorption type polarizers on the projection side substrate 11A and incident side polarizer 11B; and a screen, are arranged. Here, the liquid crystal layer 13 was a twisted nematic layer having a twist of 90 degrees and an anisotropic index of refraction Δ nd of 0.4 μm. Both of the transparent substrates 11A, 11B were a glass substrate of Corning 7059, and its thickness was 0.7 mm. The screen 10 must maintain polarization when it is arranged at inside of the absorption type polarizer 14A. As the absorption type polarizer, the polarizer G1220DU made by Nitto Denko Co. was used. In FIG. 1, in order to align the liquid crystal in a definite direction, alignment layer, electrodes for applying electric fields to the liquid crystal layer, switching element, wiring, and others are omitted. The size of a pixel was 100 μm X 300 μm for each of RGB. The pixel was arranged so that the major axis was directed in a direction perpendicular to the figure. As the liquid crystal layer 13, any one of homogeneous directivity,

twisted directivity, and homeotropic directivity can be used for initial directivity (no voltage is applied). Any one of the homogeneous directivity and the twisted directivity can be used for the liquid crystal having a positive dielectric anisotropy, and the homeotropic directivity is used for the liquid crystal having a negative dielectric anisotropy. The twisted directivity is represented by the twisted directivity of 90 degrees, but it is not restricted to it.

Details of the screen 10 of the present embodiment are indicated in FIG. 2 - FIG. 4.

The screen 10 is in a spherical shape, and composed of beads 10A having an index of refraction of 1.7 and black absorbers 10B. In accordance with the screen 10, the beads 10A and the black absorbers 10B are arranged so as to form a closest packing structure as indicated in FIG. 4. When the screen 10 is viewed from the projection side, small apertures indicated by 10 C are distributed, and other regions are occupied with the black absorber 10B. Incident light 101A at a normal angle to the screen 10 is focused to the aperture 10C depending on the incident angle to the beads 10A and the index of refraction, and projected 101B with being broadened from the screen 10. On the other hand, oblique incident light 102A to the screen 10 is absorbed by the black absorber 10B, and not projected. Accordingly, in accordance with the above composition, the oblique incident light, which decreases the resolution of the image, can be absorbed. Although

the display is used in an environment such as an office environment in the presence of an ambient light, almost all the ambient light 150A is absorbed, because the screen 10 is mostly covered with the absorber 10B when the screen is viewed from the display plane side as indicated in FIG. 3 and FIG. 4, and only a reflection component 150B from the aperture 10C is reflected. Accordingly, a composition can be obtained; whereby black brightness of the display is increased, and the contrast ratio is not decreased, even in an environment in the presence of the ambient light. In accordance with the present embodiment, the screen arranging spherical beads was used, but semi-spherical micro-lens array could be used. Furthermore, for instance, stripe shaped rod-lens having a widening effect of the viewing angle at least in a direction having a strong directivity of the illumination device 50 may be arranged.

In accordance with the present embodiment, a composition was formed by intersecting the stripe groove direction of the waveguide 53 perpendicularly with the groove direction of the light control element 40, and aligning the stripe groove direction of the waveguide 53 in parallel with the direction of the polarized light transmission axis of the reflective polarizer 30. Because the light 110A projected from the waveguide 53 contains a large portion of polarized light in a direction perpendicular to the figure, and the polarized light transmission axis of the reflective polarizer 30 is

aligned with it, the light 110A is transmitted 110B efficiently, and projected into the liquid crystal display element 20. Furthermore, because the conversion axis of the light control element 40 is aligned, the reflected light 110C, i.e. a linearly polarized light intersecting perpendicularly with the 110B, is converted effectively to the circularly polarized light by the birefringent medium 60. Then, the circularly polarized light is reflected by the reflector 54, transmitted through the birefringent medium 60 again to be the linearly polarized light 110D as same as the 110B, and becomes the incident light 110E to the liquid crystal display element 20. As the result, the efficiency of the light utilization can be increased by 20 % or more in comparison with the structures indicated in FIG. 39, and FIG. 41. The resolution of the display device of the present embodiment was high, and display having a wide viewing angle in comparison with the conventional liquid crystal element, no grayscale reversal which was scarcely observed on conventional liquid crystal element, and color shift and contrast ratio scarcely depending on the viewing angle could be obtained.

Details of the embodiment in FIG. 1 are indicated in FIG. 5 and FIG. 6.

The present embodiment was composed by arranging slow axis 61 of the birefringent medium 60 so as to form an angle of approximately 45 degrees with the fine stripe groove direction of the illumination device 50, and

arranging the stripe groove direction 41 of the light control element 40 so as to be approximately in parallel with the fine stripe groove direction of the waveguide 53. As the result, the illumination device 50 having a high collimated light in the stripe groove direction 41, and an enhanced collimation in the polarized light transmission direction 14AA could be obtained. Because the light projected from the waveguide 53 has high polarized light component in the stripe groove direction, The birefringent medium 60 may be arranged between the waveguide 53 and the reflector 54. The polarized light transmission axis 14BB of the incident side reflector of the liquid crystal display element 20 was intersected perpendicularly with the polarized light transmission axis 14AA of the projection side reflector as indicated in FIG. 5, the polarized light transmission axis 31 of the reflective polarizer 30 was made approximately in parallel with the 14BB, and the polarized light transmission axis 31 was arranged so as to intersect perpendicularly with the stripe groove direction 41 of the light control element 40, in order to obtain the composition of the present embodiment. In accordance with the composition, the light projected from the waveguide 53 is converted to the projected light 110B, 110E, on which the polarizing conversion can be performed effectively by passing only once the processes of 110C, 110D as stated previously. When the light control element 40 has birefringence, it is desirable to make the light

control element 40 and the birefringent medium 60 operate as the quarter wave plate, or the optical axis is aligned with the linearly polarized direction so as to make the birefringence of the light control element 40 be negligible.

In the embodiment indicated in FIG. 1, the polarizer 31 of type 1 indicated in FIG. 10 was used as the reflective polarizer 30. However, the most optimum structure including the reflective polarizer type 2, when the light control element is used, and its detailed embodiments are indicated in FIG. 15 and FIG. 16.

First, the illumination device using the reflective polarizer 31 of type 1 as the reflective polarizer 30 is indicated in FIG. 15.

The cross section of the present embodiment differs from the cross section indicated in FIG. 1 in its cutting direction, and indicates the cross section in a direction rotated 90 degrees at azimuthal angle from the cross sectional direction indicated in FIG. 1.

The composition indicated in FIG. 15 comprises: reflector 54 arranged at the rear plane of the waveguide; birefringent medium 60, light control element 40, and reflective polarizer 31 arranged on the waveguide.

The light 130 projected from the waveguide is projected light having a large polarized component in parallel to the figure, directed toward a normal angle by the light control element 40, and transmitted 131 through the reflective polarizer 31. On the other hand,

the linearly polarized light 132 intersecting perpendicularly with the transmitted light 131, reflected by the reflective polarizer 31, is transmitted and refracted by the light control element, and becomes circularly polarized light 133 by transmitting the birefringent medium 60. At that time, the birefringent medium 60 operates as the quarter wave plate to the oblique incident light. The circularly polarized light 134 reflected from the reflector 54 is circularly polarized light rotated in a direction reverse to the circularly polarized light 133. The circularly polarized light 134 is converted to linearly polarized light by the birefringent medium 60, and refracted by the light control element 40. The refracted light 135 has the same transmission axis as the polarized light transmission axis of the reflective polarizer 31, and becomes the projected light 136. As described above, the polarizing conversion can be realized effectively by passing only once.

Next, the illumination device using the reflective polarizer 33 of type 2 as the reflective polarizer 30 is indicated in FIG. 16.

The cross section of the present embodiment indicates the cross section in a direction rotated 90 degrees in azimuthal angle from the cross sectional direction indicated in FIG. 1, as same as FIG. 15.

The composition comprises: reflector 54 arranged at the rear plane of the waveguide; birefringent medium 61A,

61B; light control element 40, retardation plate 33A composing the reflective polarizer 33, and cholesteric layer 33B arranged on the waveguide.

The light 180 projected from the waveguide is projected light having a large polarized component in parallel to the figure, directed toward a normal angle by the light control element 40, transmitted 181 through the cholesteric layer 33B, and converted to the linearly polarized light by the retardation plate 33A. On the other hand, the circularly polarized light 182 rotated in a direction reverse to the transmitted light 181, reflected by the cholesteric layer 33B, is converted to the linearly polarized light 184 by the birefringent medium 61A, transmitted and refracted by the light control element 40, and becomes circularly polarized light 185 by transmitting the birefringent medium 61B. At that time, the birefringent medium 61B operates as the quarter wave plate to the oblique incident light. The circularly polarized light 186 reflected from the reflector 54 is circularly polarized light rotated in a direction reverse to the circularly polarized light 185. The circularly polarized light 185 is converted to linearly polarized light by the birefringent medium 61B, and refracted by the light control element 40. The refracted light 187 is converted to the circularly polarized light 187 by the birefringent medium 61a, and transmitted through the cholesteric layer 33B. The circularly polarized light 189 becomes the same linearly polarized light as the

transmitted light 182 by the retardation plate 33A, and projected. As described above, the polarizing conversion can be realized effectively by passing only once.

An embodiment for obtaining bright display with low consuming power by eliminating absorption loss by the conventional color filters and improving the efficiency of light utilization is indicated hereinafter.

The composition of the present embodiment comprises cholesteric layer 73, two layered cholesteric layer 72 having twist reverse to the cholesteric layer 73 as reflective color selective layer 70, retardation plate 71 operating as a quarter wave plate, and screen 10 arranged at upper portion of the liquid crystal display element 20. Other components are as same as FIG. 1 indicated in FIG. 20.

In FIG. 17, the reflective color selective layer 70 transmits specified polarized light having a specified wavelength, and reflects light other than the specified polarized light. For instance, the reflective color selective layer 70 transmits one of three primary colors, i.e. red, green, and blue, and reflects other colors. The cholesteric layer 73 transmits one of circularly polarized light in at least visible wavelength region, and reflects another circularly polarized light. As described above, the liquid crystal layer display device capable of re-utilizing light reflected from each of the layers 70, 73, having a low absorption loss and a high efficiency of light utilization can be realized by

arranging the cholesteric layer 73, the reflective color selective layer 70, and the liquid crystal display element 20 on the illumination device 50.

Next, an embodiment of the liquid crystal display device using the illumination device indicated in FIG. 21 is explained referring to FIG. 20.

The illumination device relating to the present embodiment has a composition comprising stripe shaped microgrooves provided at rear plane of the waveguide 53 as indicated in FIG. 21, light source 51 and lamp cover 52 provided at side plane of the waveguide 53, and reflector 54 arranged at rear side of the waveguide 53.

The projection characteristics of the illumination device 50 of the present embodiment has a high directivity in a direction intersecting perpendicularly with the stripe shaped grooves, and an extension in a direction in parallel with the stripe shaped grooves. The projection characteristics is indicated qualitatively as 300, 301 in FIG. 21.

The projection characteristics of the illumination device 50 shown in FIG. 21 is indicated in FIG. 30.

The characteristics in the direction in parallel with the direction of the stripe shaped fine grooves to the waveguide 53 is indicated as 25A, and the characteristics in the direction perpendicular to the above is indicated as 25B. In accordance with FIG. 30, it could be concluded that the collimation at all azimuth was sufficiently enhanced.

An embodiment using the illumination device 50 is indicated in FIG. 20.

The direction of the stripe shaped grooves of the waveguide 53 was intersected perpendicularly with the groove direction of the light control element 40, and the direction of the stripe shaped grooves of the waveguide 53 was aligned with the direction of the polarized light transmission axis of the reflective polarizer 30. The polarized light component in the direction parallel with the stripe shaped groove in the light projected from the waveguide is significant, transmitted effectively because it is aligned with the direction of the polarized light transmission axis of the reflective polarizer 30, and projected into the liquid crystal display element 20. The conversion axis of the light control element 40 is composed so as to be approximately in parallel with the polarized light transmission axis of the reflective polarizer 30. In accordance with the above composition, the polarizing conversion can be achieved effectively and the efficiency of the light utilization can be increased significantly, because the direction having a high polarized light component from the waveguide 53 is coincided each other. The resolution of the display device of the present embodiment is high, and display having a wide viewing angle in comparison with the conventional liquid crystal element, no grayscale reversal which is scarcely observed on conventional liquid crystal element, and color shift and contrast ratio

scarcely depending on the viewing angle can be obtained.

Next, operation of the reflective color selective means 70 and the reflective polarizing selective means 73 relating to the present invention are explained in details referring to FIG. 18.

As an example of the reflective color selective means 70, cholesteric layers 72A-72C utilizing selective reflection of the cholesteric, and retardation plate 71 operating as quarter wave plate are used. The retardation plate 71 may be arranged for every color as same as the cholesteric layer 72 in order to operate as a quarter wave plate with every color. As the reflective polarizing light selective means 73, for instance, the cholesteric layer having specified reflection for at least three primary colors is used, and the cholesteric layer 73 has the twist reverse to the cholesteric layers 72A-72C. The cholesteric layers 72A-72C as the reflective color selective means 70, the retardation plate 71, and the cholesteric layer as the reflective polarizing light selective means are arranged on the illumination device comprising wave guide means and the reflection means.

Using the cholesteric layer as the reflective polarizing light selective means 73 has been known, and the technology disclosed in JP-A-3-45906 (1991), and JP-A-6-324333 (1994) can be applied. Selective reflection wavelength λ by the cholesteric layer can be expressed by the following equation:

$$\lambda = (n_0 + n_1)/2P$$

The selective reflection wavelength λ is determined by cholesteric spiral pitch P, the index of refraction of ordinary light n_0 , and of extraordinary light n_e . Selective reflection band $\Delta\lambda = \Delta nP$ is determined by an anisotropy of refractive index $\Delta n = n_e - n_0$ and the spiral pitch P. However, Δn is approximately 0.3, and all the visible region can not be covered. Accordingly, all the visible region must be covered by laminating several cholesteric layers having different pitches each other, or varying the pitch in the cholesteric layer. As materials for the cholesteric layers 72A - 72C as the reflective color selective means 70, the same materials as the reflective polarizing light selective means 73 can be used, and the spiral pitch for each of the layers is set so as to make specified reflection such as red, green, and blue. Although selective reflection center wavelength, and selective reflection band are not restricted, each of center wave length is desirably selected as 470 nm, 550 nm, and 620 nm, and the desirable specified reflection band is approximately $\pm$ 35 nm.

Conveniently, the cholesteric layers 72A - 72C are assumed to be twisted at right-handed, and the cholesteric layer 73 used as the reflective polarizing light selective means 73 is assumed to be twisted at left-handed. Accordingly, the cholesteric layer 73 reflects the left-handed circularly polarized light, and transmits the right-handed circularly polarized light. Each of the

cholesteric layers 72A - 72C reflects the right-handed circularly polarized light of red color, green color, and blue color, respectively, and transmits other colors.

The light 200 projected from the waveguide means made of transparent acrylic resin is white non-polarized light is projected into the cholesteric layer 73, i.e. the reflective polarizing light selective means. Then, the transmitted light becomes white right-handed circularly polarized light 201, and the reflected light becomes white left-handed circularly polarized light 203. The white right-handed circularly polarized light 201, i.e. the transmitted light, is projected into the cholesteric layers 72A, 72C, where right-handed circularly polarized light 202 of green color is transmitted, and blue and red color right-handed circularly polarized lights 206 are reflected. The transmitted green color right-handed circularly polarized light 202 becomes green color linearly polarized light 213 by the retardation plate 71.

On the other hand, the reflected white left-handed circularly polarized light 203 is further reflected by the reflecting means 54 arranged at rear plane of the waveguide means to be left-handed circularly polarized light 207, and is transmitted through the cholesteric layer 73. The white right-handed circularly polarized light 207 transmitted through the cholesteric layer 73 is projected into the cholesteric layers 72B, 72C, and only red color right-handed circularly polarized light 205 is transmitted and other left-handed circularly

polarized light 211 is reflected. The transmitted red color right-handed circularly polarized light 205 is converted to red color linearly polarized light 214 in the same polarizing axis with green color linearly polarized light 213 by the retardation plate 71.

The reflected blue color and red color right-handed circularly polarized light 206 is reflected by the reflection means 54 to be blue color and red color left-handed circularly polarized light 207, reflected by the cholesteric layer 73 as blue color and red color left-handed circularly polarized light 208, and reflected by the reflection means 54 again to be right-handed circularly polarized light 209. The right-handed circularly polarized light 209 is transmitted through the cholesteric layer 73, projected into the cholesteric layers 72A, 72B, and only blue color right-handed circularly polarized light 210 is transmitted through the cholesteric layers and the rest is reflected. The transmitted blue color right-handed circularly polarized light 210 is converted to the linearly polarized light 215 in the same direction with the linearly polarized light 213, 214 by the retardation plate 71. Here, an example for explanation was taken with a case when the waveguide means 53 and the reflection means 54 did not have any depolarization by scattering. However, when the depolarization is existed, the light can be re-utilized by repeating transmission of only desired polarized light component and reflection of undesired polarized light

component.

The reflected light 211, 212 by the cholesteric layer, i.e. a reflective color selective layer, can be re-utilized by the same phenomena as above.

Operations of the reflective color selective means 70 and the reflective polarizing selective means 73 are explained, hereinafter.

As an example of the reflective color selective means 70, the dielectric multilayered film 74A - 74C are utilized; the dielectric multilayered film transmits one of perpendicularly intersecting linearly polarized lights and reflects the rest of the linearly polarized lights. As the reflective polarizing selective means, the dielectric multilayered film 73B is used; the reflective polarizing selective means transmits one of perpendicularly intersecting linearly polarized lights for three primary colors and reflects the rest of the linearly polarized lights. The dielectric multilayered film 74A - 74C and the dielectric multilayered film 73B are arranged so that the polarizing axis of their polarized lights are approximately same. The dielectric multilayered film 74A - 74C as the reflective color selective means 70 and the dielectric multilayered film 73B as the reflective polarizing selective means are arranged on the illumination device comprising the waveguide means and the reflection means. Desirably, the retardation plate 61C operating as a quarter wave plate to each of the wavelength is arranged between the

dielectric multilayered film 73B and the reflection means 54. Preferably, the retardation plate 61C is used; the retardation plate is adjusted with phase difference to each of the color by making its shape stripe corresponding to the layers of the reflective color selective means. Furthermore, preferably, the light control element 40 may be arranged in order to enhance the directivity of the transmitted light.

Using the dielectric multilayered film as the reflective polarizing selective means has been known, and the technology disclosed, for instance, in WO95/27919 can be applied. The dielectric multilayered film 74A - 74C as the reflective color selective means 70 can be composed of the same materials as the reflective polarizing selective means, each of the layers is set so that one of perpendicularly intersecting linearly polarized lights of red, green, and blue and reflects the rest of the linearly polarized lights.

For convenience of explanation, the linearly polarized light in a perpendicular direction to the figure is expressed by the mark +, and the linearly polarized light in a lateral direction to the figure is expressed by the mark -.

The light 200 projected from the waveguide means made of transparent acrylic resin is white non-polarized light is projected into the dielectric multilayered film 73B, i.e. the reflective polarizing selective means. Then, the transmitted light becomes white linearly polarized

light +201A, and the reflected light becomes white linearly polarized light -203A. The white linearly polarized light +201A, i.e. the transmitted light, is projected into the dielectric multilayered film layers 74A, 74C, where green color linearly polarized light +202A is transmitted, and blue and red color linearly polarized lights +209A are reflected.

On the other hand, the reflected white linearly polarized light 203A is converted to the right-handed circularly polarized light 204A by the retardation plate 61C, reflected by the reflection means 54 arranged at rear plane of the waveguide means 53 to be the left-handed circularly polarized light 205A, transmitted through the retardation plate 61C to be converted to the linearly polarized light +206A, and transmitted through the dielectric multilayered film layer 73B to be the linearly polarized light +207A. The linearly polarized light +207A transmitted through the dielectric multilayered film layer 73B is projected into the dielectric multilayered film layers 74B, 74C, only red color linearly polarized light + 208A is transmitted, and other linearly polarized light +218A is reflected and re-utilized by the same processes.

The reflected blue color and red color linearly polarized light + 209A is converted to the left-handed circularly polarized light 210A by the retardation plate 61C, reflected by the reflection means 54 to be blue color and red color right-handed circularly polarized light

211A, projected again into the retardation plate 61C to be the linearly polarized light -212A. The linearly polarized light -213A reflected by the dielectric multilayered film layer 73B is converted to the right-handed circularly polarized light 214A by transmitting the retardation plate 61C, reflected by the reflection means 54 to be left-handed circularly polarized light 215A, transmitted through the retardation plate 61C again to be the linearly polarized light + 216A, and transmitted through the dielectric multilayered film layer 73B. The linearly polarized light +216A, i.e. the transmitted light, is projected into the dielectric multilayered film layers 74A, 74B, only + blue color linearly polarized light is transmitted through the dielectric multilayered film layers and the rest is reflected to be the reflected light 219A, and re-utilized by the same principle. Here, an example for explanation was taken with a case when the waveguide means and the reflection means 54 did not have any depolarization by scattering. However, when the depolarization is existed, the light can be re-utilized by repeating transmission of only desired polarized light component and reflection of undesired polarized light component.

The operations of the reflective color selective means 70 and the reflective polarizing selective means 73 have been explained as above referring to FIG. 18 and FIG. 19. However, the cholesteric layer for the reflective color selective means 70 and the dielectric multilayered film

layer for the reflective polarizing selective means 73, or the dielectric multilayered film layer for the reflective color selective means 70 and the cholesteric layer for the reflective polarizing selective means 73 can be used, and the combination is not restricted by the above explanation.

Because the viewing angle characteristics of the reflective polarizing selective means 73 explained above referring to FIG. 18 and FIG. 19 is generally inferior to the absorption type polarizer (the polarization is shifted from the desired polarization by oblique incident light), it is desirable to arrange an absorption type polarizing selective means 14B at the incident light plane of the liquid crystal element as indicated in FIG. 26, if necessary in matching to the collimation of illuminated light from the illumination device. Furthermore, because the viewing angle characteristics of the reflective color selective means 70 is generally undesirable, and the polarization is shifted from the desired polarization by oblique incident light; it is desirable to arrange color filters as the absorption type color selective means in the liquid crystal element, if necessary in matching to the collimation of illuminated light from the illumination device. Furthermore, in order to compensate viewing angle dependence of the reflective color selective means 70, using the screen indicated in FIG. 2-FIG. 4 for absorbing the oblique incident light is desirable. In order to compensate

viewing angle dependence of the reflective color selective means 70, pigment and the like for absorbing colors other than the desired color can be used by mixing or laminating.

Furthermore, display having a wide viewing angle, no color mixing between the reflective color selective means can be obtained by arranging the reflective color selective means in stripe shape, using the illumination device having an directivity of the light in a direction perpendicularly to the stripe direction, and diffusing only in a direction along the directivity of the light at the display plane. When the reflective color selective means is arranged in stripe shape, deterioration of the image quality by mixing colors between pixels can be eliminated with providing no directivity of the light in the stripe direction. Not only the amount of the projected light from the illumination device itself can be increased, but also its structure can be simplified by enhancing its collimation of the illuminated light in a direction of the illumination device. For instance, the lens sheet at the upper portion of the waveguide can be eliminated by setting the stripe fine grooves of the illumination device approximately in parallel to the stripe direction of the reflective color selective means.

Change in characteristics (color shift, polarization change) of the reflective color selective means with oblique incident light can be compensated and display having a high color reproduction with the oblique incident

light can be obtained by arranging a second absorption type polarizing selective means at the liquid crystal layer side of the reflective color selective means. Even if collimation of light sources in the stripe direction is worse, problems such as mixing color and others can be eliminated because colors in the stripe direction are same color, and color liquid crystal display device having a high efficiency in light utilization can be realized by enhancing its directivity of the light without deteriorating the efficiency of the light utilization.

Further desirably, display having a high image quality even with the oblique incident light from the direction, where diffusion by the diffuser at the display plane is not performed, can be obtained by using liquid crystal display mode having a wide viewing angle in the stripe direction of the reflective color selective means. Further desirably, composition of the illumination device can be facilitated by arranging the longitudinal direction of the lamp and the stripe direction of the color selective means in approximately parallel each other.

By using the above means, problems such as deterioration of the image quality depending on the thickness of the substrate, deterioration in the contrast ratio and display performance such as displayed color with the oblique incident light can be prevented, and bright display device having low consuming power and small absorption loss can be obtained. That is, wide viewing angle can be realized by transmitting the light

transmitted through the reflective color selective means and the liquid crystal layer in approximately perpendicular to the substrate, and diffusing optically at the display plane. Therefore, the problems with the oblique incident light, which have been problems for a long time, can be solved, and the display device having a wide viewing angle, and no deterioration of the image quality depending on the viewing angle can be realized. Furthermore, the reflected light from the reflective color selective means and the reflective polarizing selective means can be used effectively, and efficiency of the light utilization can be achieved by re-utilization of the light.

Hereinafter, advantages and the operation of the embodiment referring to FIG. 17 using the reflective color selective means for decreasing the absorption loss of the color filters, improving the efficiency of the light utilization, and realizing the bright display with low consuming power are explained. In accordance with conventional illumination device, various problems such as unclearness of image, and color mixing. Therefore, the reflective color selective layer 70 had a structure of stripe shape (pitch of 100 μm in matching with pixel) in a direction perpendicularly to the figure in matching with the pitch of the liquid crystal layer 13. The illumination device 50 used in the present embodiment had a high directivity of the light in a direction lateral to the figure, that is, projection light characteristics

having a high collimated light. Accordingly, the direction perpendicular to the stripe of the reflective color selective layer 70 had a high collimated light, the light transmitted through the reflective color selective layer 70 transmitted the pixel corresponding to the same color, the light transmitted through the pixel was extended in a lateral direction to the figure by the screen 10 at the upper portion, and the display having wide viewing angles with no unclearness of images, no decrease in contrast ratio, nor decrease in purity of colors could be obtained. On the other hand, the direction perpendicular to the figure requires not necessarily high collimation of the light source for displaying same color, and the projected light from the illumination device 50 is used without collimation. However, in consideration with the viewing angle dependence of the reflective color selective layer 70, providing the directivity of the light to the illumination device is necessary. The light projected from the illumination device 50 must be extended at least in the direction collimated strongly, and the direction perpendicular to the above direction is not necessarily extended by the screen 10. Therefore, the color mixing depending on the thickness of the glass substrate could be eliminated by increasing the collimation of the light at least in the direction perpendicular to the stripe of the reflective color selective layer 70, and the display having the wide viewing angle became possible. In accordance with the

present embodiment, the characteristics having no color mixing and a high contrast ratio was obtained.

In accordance with the present embodiment, the display having a wide viewing angle without making the image unclear could be realized, as described above. The efficiency of the light utilization was significantly improved, because the absorption loss by the conventional polarizer and color filters was decreased. Although the light projected from the waveguide 53 is non-polarized light, one of the circularly polarized light is transmitted through the cholesteric layer 73, and other circularly polarized light is reflected. The transmitted circularly polarized light receives color selection by the reflective color selective layer 72 to be transmitted only the circularly polarized light of the desired color (other color is reflected). The transmitted light is converted to the linearly polarized light by the retardation plate 71, modulated by the liquid crystal layer 13, selected by the absorption type polarizer 14A, and displayed corresponding to image signals. On the other hand, other circularly polarized light reflected by the cholesteric layer 73 is further reflected by the reflector at the rear plane of the waveguide to be the circularly polarized light in a reverse direction. The circularly polarized light is transmitted through the cholesteric layer 73 , and used for the display. Similarly, the reflected light of the other color is re-utilized when projected into the desired

color selective layer after repeating reflections by the reflector 54 at the rear pane of the waveguide. Accordingly, although the reflector 54 and the selective layer 72 had somewhat absorption loss, theoretically all the light could be re-utilized, and the efficiency of the light utilization was improved remarkably. In accordance with the present embodiment, the efficiency of the light utilization was increased by approximately 3.5 times in comparison with a case having no cholesteric layer 73 nor color selective layer 72.

Next, an embodiment of the illumination device having high uniaxial collimation and collimation at all azimuth is explained. The illumination devices explained hitherto can be used naturally, but other embodiment is indicated, hereinafter.

As the embodiment of the illumination device 50A, a lens sheet 40 was used as the light control element having a cross section of stripe shaped triangles on the illumination device 50 indicated in FIG. 22 to make the device have characteristics having directivity in a depth direction of the figure. In accordance with the present embodiment, the apex angle 40A was 90 degrees and the pitch was 50 μm, but the apex angle and the pitch are not restricted by these values. As the result, the directivity was enhanced at all azimuth as indicated by lateral direction projection characteristics 300A and vertical direction projection characteristics 301A, and the collimation could be improved. The projection

characteristics at the time is indicated in FIG. 31; wherein the lateral direction projection characteristics 25D has been widened slightly, and the directivity in the vertical direction projection characteristics 25C has been enhanced. By applying the illumination device 50A to the liquid crystal display device indicated in FIG. 17, the brightness at a normal angle was improved by the directivity of the light, and the color reproduction depending on viewing angle was improved by decreasing the oblique incident light in the stripe direction of the reflective color selective layer. At that time, transmitted light through the liquid crystal layer 13 could be widened at all azimuth by arranging the screen indicated in FIG. 2, FIG. 3, and FIG. 4 as the screen 10, and the viewing angle characteristics could be improved. In accordance with the present embodiment, the characteristics having no color mixing and a high contrast ratio could be obtained.

An embodiment of the illumination device 50B is indicated in FIG. 24; wherein a collimating sheet 41 indicated in FIG. 23 was used instead of the lens sheet. The collimating sheet 41 was made of transparent acrylic resin having narrowed bottom portion arranged in stripe manner, and its shape of the pitch 4 mm, height 4 mm, and bottom length 1mm was used. However, if the collimating sheet has a structure, wherein the bottom portion is narrow and the width of the portion is widened as it comes close to the upper portion, the shape is not restricted

by the above values. As the result, the incident light to the bottom of the collimating sheet 41 had the characteristics such as 300B, wherein the directivity was enhanced only in the lateral direction of the figure, and the light is widened in the depth direction of the figure reflecting the incident light viewing angle characteristics indicated by 301B. The collimating sheet 41 was arranged so that the stripe direction of the sheet was intersected perpendicularly with the groove direction of the illuminating device 50, and the waveguide 53 and the collimating sheet 41 were adhered each other by a transparent medium having an approximately same refractive index. As the result, the light reflected from the declined microgroove portion at the rear plane of the waveguide 53 is projected, and further, even the other light, which would be reflected and propagated in the waveguide 53 when the collimating sheet is not existed, is projected out when the light is projected into the bottom plane of the collimating sheet 41. Accordingly, the projection characteristics in the lateral direction 300C is made in parallel by the microgrooves at the rear plane of the waveguide 53, and the projection characteristics in the vertical direction 301C is made in parallel by the collimating sheet 41. Desirably, the adhered portion of the collimating sheet 41 is not the whole plane of the bottom, but some portions adhered with an intervals in parallel to the microgrooves at the rear plane of the waveguide 53. By applying the illumination

device 50B to the liquid crystal display device indicated in FIG. 17, the brightness at a normal angle was improved by the directivity of the light, and the color reproduction depending on viewing angle was improved by decreasing the oblique incident light in the stripe direction of the reflective color selective layer 70.

The other embodiment of the liquid crystal display element 20 is explained, hereinafter.

An embodiment of the liquid crystal display element 20 is indicated in FIG. 25.

The same structure as the liquid crystal display element indicated in FIG. 18 was used as the illumination device 50. However, any of the other illumination devices used hitherto can be used.

The different points from the embodiment indicated in FIG. 18 is in the arrangement of the reflective color selective layer 70 and the reflective polarizing selective layer 73 at inside the transparent substrate 11B. The important point of the present embodiment is in the arrangement of the reflective color selective layer 70 at inside the transparent substrate, and the reflective polarizing selective layer 73 may be arranged at the illumination device side of the transparent substrate 11B, because the adjustment of pixels is not necessary. In FIG. 25, the thickness of transparent substrates 11A, 11b are the sources making the image unclear. That is, if the collimation of the light projected from the illumination device is not desirable, pixels of the

reflective color selective layer 70 and the liquid crystal layer 13 are transmitted through different regions each other, and mixing color and others are generated. In accordance with the structure composed of as the present embodiment, the influence of the thickness of the transparent substrate 11B can be eliminated, and clear image can be obtained even if the collimation of the illumination device 50 is not desirable.

The other embodiment of the liquid crystal display element 20 is indicated in FIG. 26.

The same structure as the liquid crystal display element indicated in FIG. 18 was used as the illumination device 50. However, any of the other illumination devices used hitherto can be used.

The different points from the embodiment indicated in FIG. 18 is in the arrangement of the absorption type polarizing selective layer 14B between the transparent substrate 14 and the reflective color selective layer 70. The polarizer G1220DU made by Nitto Denko Co. was used as the absorption type polarizing selective layer 14B. In accordance with the present embodiment, cholesteric layers are used as the reflective color selective layer 70 and the reflective polarizing selective layer 73, and the polarization and the viewing angle dependence of the polarized light are inferior in comparison with the absorption type polarizer. Accordingly, by arranging the absorption type polarizer 14B on the reflective polarizing selective layer 73 and the reflective color

selective layer 70, unnecessary polarized light from the layer 70 can be absorbed by the absorption type polarizer 14B, and the polarized light characteristics of the transmitted light is improved and the contrast ratio of the display can be improved.

The other embodiment of the liquid crystal display element 20 is indicated in FIG. 27.

The same structure as the liquid crystal display element indicated in FIG. 26 was used as the illumination device 50. However, any of the other illumination devices used hitherto can be used.

The different points from the embodiment indicated in FIG. 26 is in the arrangement of the absorption type polarizer 14B between the transparent substrate 11B and the reflective color selective layer 70. The polarizer G1220DU made by Nitto Denko Co. was used as the absorption type polarizer 14B. In accordance with the present embodiment, cholesteric layers are used as the reflective color selective layer 70 and the reflective polarizing selective layer 73, and the polarization and the viewing angle dependence of the polarized light are inferior in comparison with the absorption type polarizer. Accordingly, by arranging the absorption type polarizer 14B on the reflective polarizing selective layer 73 and the reflective color selective layer 70, unnecessary polarized light from the layer 70 can be absorbed by the absorption type polarizer 14B, and the polarized light characteristics of the transmitted light is improved and

the contrast ratio of the display can be improved. Clearer image could be obtained in comparison with the case indicated in FIG. 26.

In accordance with the above embodiments, the explanation was performed on the composition wherein the color filter, i.e. the absorption type color selective means, was eliminated. However, the color filters may be arranged in order to improve color purity. The color reproduction of the displayed color can be improved by arranging the color filters.

Another embodiment of the screen 10 is explained, hereinafter.

An example of the characteristics of the screen 10 is indicated in FIG. 28. In the previous embodiment, Lumisty made by Sumitomo Chemical Co. can be used as the uniaxial optical diffusion layer having projection characteristics as indicated as 302A in the lateral direction and as indicated as 303A in the vertical direction, as the screen 10. In the present embodiment, a stripe shaped rod lens array (its pitch is approximately 50 μm) as indicated in FIG. 29 was used as the screen 10 D having an uniaxial scattering property. The illumination device 50 used in the present embodiment had a strong directivity of the light in the lateral direction, and clear display having a wide viewing angle could be realized by widening the projected light by the screen 10D operating as the uniaxial scattering layer after transmitted through the liquid crystal layer 13.

Desirably, the absorber at projection side is arranged as indicated in FIG. 2-FIG. 4.

Hitherto, the embodiments of the liquid crystal display devices using illumination device having a high uniaxial collimated light or collimation at all azimuth, screen broadening projected light at uniaxial or at all azimuth, reflective polarizer, light control element, and reflective color selective means have been explained. Other combination of each of the above components for application is possible. The display mode of the liquid crystal is not restricted by the above embodiments.

In accordance with the present invention, the liquid crystal display device having a wide viewing angle and a high efficiency of the light utilization can be realized by using the reflective color selective means, polarizing selective means, light control element, and screen. The optimum axial arrangement of the light control element and the polarizer, when the light control element is applied in order to improve the brightness at a normal angle, is defined. Improvement of the efficiency of the light utilization and of the brightness at a normal angle can be realized by using the waveguide, which is capable of maintaining the polarization of the reflected light from the reflective polarizer and improving the directivity of the light.

Although one of the objects of the present invention is to eliminate the absorption loss by the polarizer and color filters, and improve the efficiency of the light

utilization, the present invention can provide color liquid crystal display devices having a high display quality and a wide viewing angle even if the display is viewed from an oblique position by eliminating the deterioration of the display quality (unclearness) caused by the thickness of the glass substrate, which has been a problem in prior art, and deterioration of the display quality (decrease in contrast ratio, deterioration in displayed color) in an oblique angle.

In accordance with the composition of the present invention, the liquid crystal display devices which can display with a wide viewing angle by a low consuming power can be provided.